REVISTA DE GEOMORFOLOGIE (2019) **21**: 5–14
DOI: 10.21094/rg.2019.006
www.geomorfologie.ro, http://revistadegeomorfologie.ro

The erosion of glaciated mountains: evidence from hypsoclinometry

Ian S. EVANS[1*]

[1]Durham University, Department of Geography, Lower Mountjoy, South Road, Durham, DH1 3LE, United Kingdom

Received 1 October 2019; Revised 14 November 2019; Accepted 20 November 2019
*Correspondence to: Ian EVANS e-mail: i.s.evans@durham.ac.uk

ABSTRACT

Mountain glaciation involves the erosion of cirques and troughs, which increase steep slopes but also produce gentle slopes in cirque floors and trough floors. This is expected to increase the variability of slope gradients at related altitudes. Taking a whole mountain range, its distributions of altitude and slope can be analysed to establish a signal of glacial modification. Frequency distributions of altitude (hypsometry) and gradient (clinometry) alone do not seem adequate. Taking these two variables together – hypsoclinometry, plotting slope gradient against altitude – is more promising. Frequency distributions of slope gradient at different altitudes are exemplified here for mountain ranges in British Columbia and Romania, together with altitudinal variations of steep or gentle slopes.
Cirque headwalls give the clearest morphometric signature of glaciation. Steep (especially the steepest) slopes are concentrated at cirque altitudes, increasing mean, median, standard deviation (SD) and inter-quartile range (IQR) of gradients, especially above cirque floors. There is only a small increase in SD and IQR at cirque floor altitudes. Hypsometric maxima and increased proportions of gentle slopes at cirque floor altitudes are clear only in mountain ranges densely occupied by cirques. This relates to the small proportion of each cirque (about 28%) occupied by the floor. Concentrations of steep slope aspects in directions favoured by local glaciers provide further evidence of glacial modification. The most general morphometric effect of glaciation, however, is the increase in steep slopes at cirque headwall altitudes. Thus it is possible to rank mountain ranges by degree of glacial modification.

KEYWORDS
hypsometry; clinometry; British Columbia; TanDEM–X; glacial erosion; cirque

1. Introduction

There are many differences between glaciated and unglaciated mountains, but how are these differences best expressed quantitatively? One way is to define and measure the specific landforms – cirques, arêtes, troughs and closed rock depressions – that characterize glacial erosion (Barr and Spagnolo, 2015). Their sizes and densities show the degree of glacial modification of mountain landforms. The definition of specific landforms is progressing (in efficiency and objectivity) but remains subjective (Evans and Cox, 2017). For example, in some areas it is difficult to distinguish shallow glacial cirques from deep–seated rock slope failure scars, whose deposits may have been removed by glaciation. Glacial troughs are more difficult to define: an inverted parabola (U–) shape is characteristic but alluvial valley–floors obscure the distinction from fluvial valleys and make fitting a model to the bedrock surface problematic.

Analysis of the land surface (Minár and Evans, 2016) can employ either specific or general geomorphometry, or both. Thus in seeking greater objectivity it may be interesting to check for signals of glaciation in general geomorphometry, e.g. to take a whole mountain range and measure its distributions of altitude, slope gradient, slope aspect and curvatures. To start, frequency distributions of altitude (hypsometry) and slope gradient (clinometry) have been considered. It is widely believed that that cirque erosion around glacial Equilibrium Line Altitudes (ELAs) has produced hypsometric maxima (high frequencies of altitude) (Mitchell and Montgomery, 2006; Egholm et al., 2009). This is one of the bases of the 'glacial buzz-saw' hypothesis that effective glacial erosion at such altitudes in the Late Cenozoic has worked to limit mountain altitudes (Mîndrescu and Evans, 2014). The strength of the hypsometric maximum should thus express at least one component of the glacial modification of mountains.

Hypsometric maxima, however, are somewhat fallible evidence as they may be produced in various ways (Evans et al., 2015; Robl et al., 2015, 2015a; Crest et al., 2017). It seems better to consider altitude and gradient together, rather than separately. Further evidence has thus been sought in the variation of mean or median slope gradient (slope angle) with altitude (elevation). Equilibrium models of fluvial topography predict steady increases in both channel gradient and hillslope gradient with altitude. In glaciated mountains, however, a flattening of this trend has been found at cirque floor altitudes (at least in the Alps: Kühni and Pfiffner, 2001; Robl et al., 2015a). Yet as glaciation produces gentle and reversed slopes (cirque floors and trough floors) as well as extra steep slopes (cirque headwalls and trough sides), plotting mean or median slope against altitude is not sufficient. It is necessary to plot frequency distributions of slope gradient at different altitudes. This combination of hypsometry and clinometry is logically labelled *hypsoclinometry*, and is more promising than the separate components, as the excellent work of Robl et al. (2015a) on the Alps has shown.

This leads me to a number of specific hypotheses:

1. There are more gradients <20° at cirque floor altitudes;
2. There are more gradients >35° above cirque floors (i.e. cirque headwalls);
3. Higher standard deviations (SDs) and interquartile ranges (IQRs) of gradients occur at cirque floor altitudes (because the altitude ranges of headwalls and floors overlap: headwalls are found immediately above the lowest cirque floors).

These hypotheses are tested here for two mountain ranges in British Columbia and compared with previous results from Romania.

2. Data and Methods

An increasing number of fairly accurate Digital Elevation Models (DEMs) are now available with near–worldwide coverage. For geomorphological interpretations, forest and human constructions can cause problems, but these are almost absent in mountains above timberline. In glaciated mountains, the main problems come from shadow (both solar shadow and radar shadow), glaciers and lakes.

The hypsoclinometry of 21 mountain ranges in Romania was analysed by Niculiţă and Evans (2018) from freely available SRTM data, gridded with 30 m horizontal resolution and analysed in ArcGIS.

Here I focus on data for British Columbia, extracted from TanDEM–X 1–degree tiles supplied by DLR (project DEM–METH 1517). These provide higher resolution (30 arc–second), and were gridded (by D. Milledge) at 12.5 m grid mesh. Mountain range outlines were digitised, initially for the Shulaps and Bendor Ranges on the interior side of the southern Coast Mountains, some 175 km north of

Vancouver. The data were extracted for whole mountain ranges down to the valleys and lakes on either side, and to passes separating them from other high ground. Note that below the 'defining pass' – the highest point on the range boundary – results for slope aspect become increasingly biased as contours are not closed on that side of the range. Above that pass, as each higher contour encompasses a smaller area, there is an expectation (but not an inevitability) that each contour may be shorter and that the area in each successive band (bin, class) of altitude will be less.

As the data are radar–based, return scatter over water produces false values, with differences of tens of metres between adjacent points which should be on the same level. Thus lakes had to be masked out, using available masks for large lakes but digitising other lake outlines. Lake areas were then treated as 'missing data'. (Alternatively, with more work, each lake could be given its true altitude so that it shows up as zero gradients at the appropriate altitude). The altitude data were read into Stata as (x,y,z) trios and slope gradients and aspects were calculated with a program by N.J. Cox, based on the formulae in Evans (1979).

Available (map–based) data for each cirque floor in these ranges include lowest, modal and maximum altitudes. To exclude extreme values, the lowest 5% and highest 5% are ignored, and the 05 and 95 percentiles of Lowest altitude plus the 95 percentile of Maximum floor altitude are used to

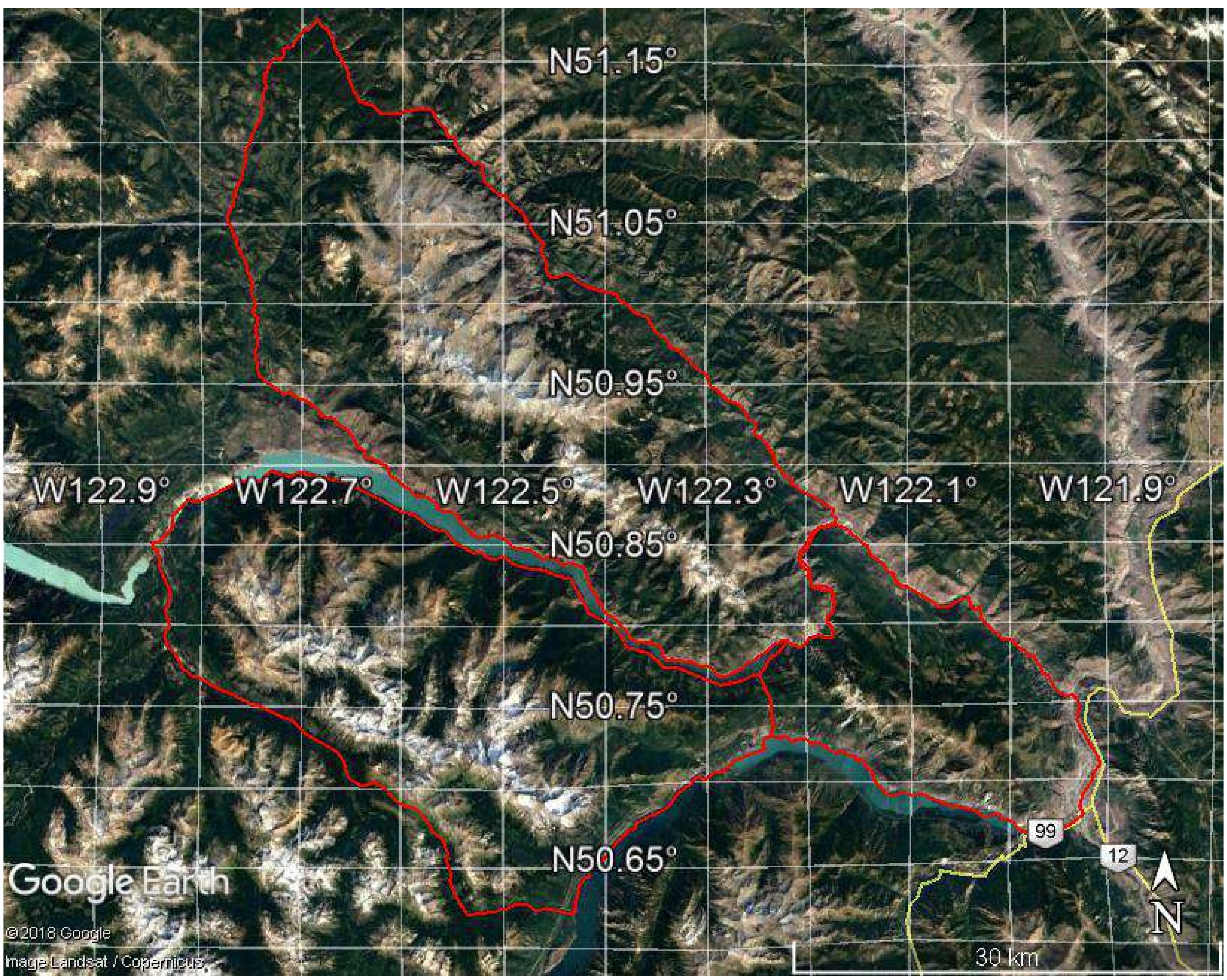

Figure 1 The Bridge River District, British Columbia. Longitude grid lines are spaced 0.1°; latitude, 0.05°. Red outlines show the Shulaps Range (top), the Bendor Range (left) and the Mission Range (right). The long central lake is Carpenter Lake (a reservoir): the north–south valley on the right is of the Fraser River

represent the altitudinal range of cirque floors. By relating results for hypsoclinometry to these previous results for cirques, available on a comparable basis for British Columbia and Romania, it becomes clear that specific geomorphometry and general geomorphometry can be complementary.

3. Results

The Bendor and Shulaps Ranges (Fig. 1) in the Bridge River District of British Columbia are on the landward side of the southern Coast Mountains, which has a much less humid climate than the seaward side. At the last glacial maximum they were submerged in the Cordilleran Ice Sheet, which flowed southward and south–westward from the Interior (Fraser) Plateau to the coast, through several passes (Evans, 1990). The Ice Sheet produced little modification of the higher ground, where it was thinner and possibly cold–based. Instead, both Ranges preserve landforms of local glaciation (cirques and troughs) which developed during the build–up of ice and in numerous previous phases of glaciation intermediate between maximum and present–day. These were mainly valley glaciers, whereas those present today are cirque glaciers no longer than 2 km (Bendor) or 1 km (Shulaps).

3.1 Shulaps

The Shulaps Range has cirques and small glaciers mainly on its north or northeast side. Cirque lowest altitudes range from 1957 to 2456 m (05% to 95%) and the 95 percentile of Maximum floor altitude is 2610 m. Figure 2 shows the altitudinal distribution of steep and gentle slope gradients. The results for low gradients are disappointing in that there is no maximum at cirque floor altitudes. This is partly because cirque floors are on average only c. 28% of cirque areas (in Romania: Mîndrescu and Evans, 2014, 2017), and partly because there is an extensive area of low–gradient bench or piedmont just below cirque altitudes, on the northeast (Yalakom) slope. Hence there is also no clear increase in SD or in IQR (Fig. 2).

Headwalls, however, give a clear 'glacial' signal – mainly above 2456 m. At 1530–1957 m, below cirque floors, only 1.5% of gradients are >45°: at 1957–2456 m the percentage rises to 2.5, at 2456–

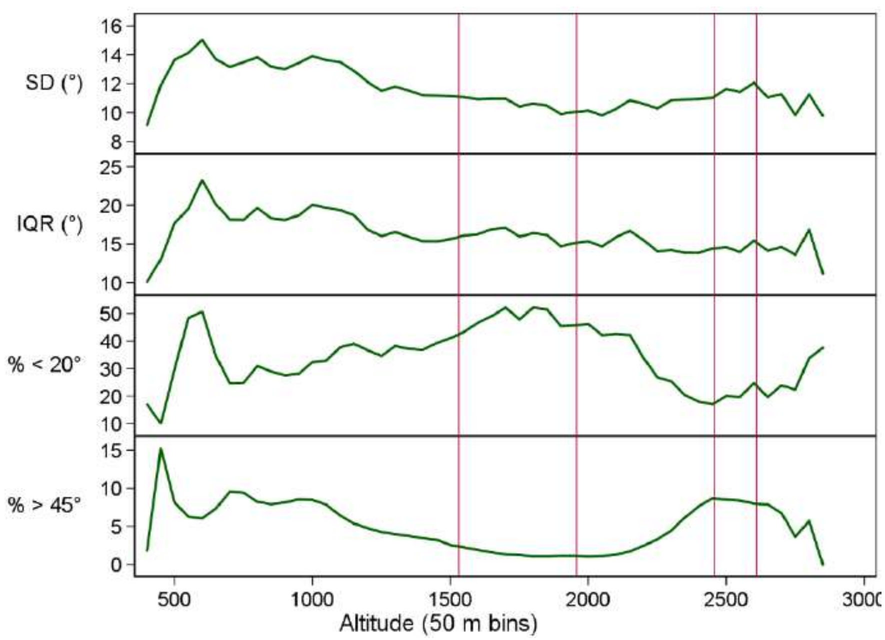

Figure 2 Shulaps Range gradient statistics by altitude: dispersion measured by Standard Deviation (SD) and Inter–quartile Range (IQR), and percentages (in each 50 m altitude bin) of gentle and steep slopes. The left red line is the defining pass; the two central lines at 1957 and 2456 m are the 05 and 95 percentiles of cirque floor *Lowest altitude*, and the right line at 2610 m is the 95 percentile of *Maximum floor altitude* per cirque

2610 m it is 8.5 and above 2610 m it is 7.5 (Fig. 2). This is a clear representation of steep cirque headwalls. Figure 3 shows the density (frequency in relation to total) of slope gradients >45°: the strong secondary mode above 2100 m altitude shows cirque headwalls even more clearly.

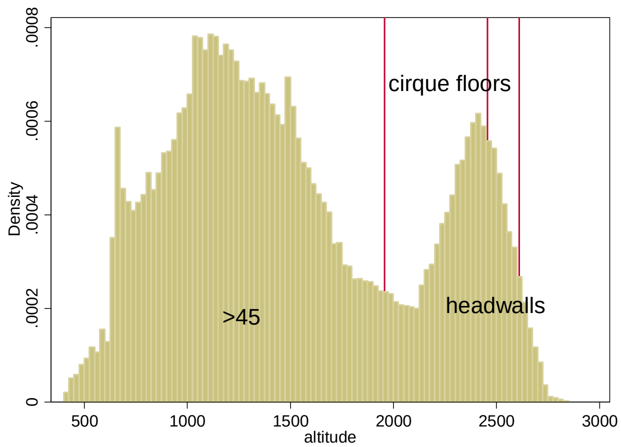

Figure 3 Density of steep gradients (>45°) in the Shulaps Range by altitude (50 m bins)

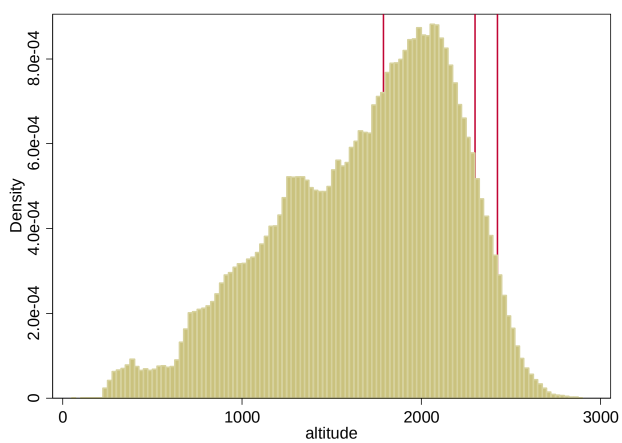

Figure 4 Density of altitude in the Bendor Range (25 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floors, covering the hypsometric maximum

Vector analyses of aspects of steep slopes provide further evidence of glacial modification of the Shulaps Range. Using the same altitude classes as above, but subdividing the large 1957–2456 m class, vector means are consistently northward (351–001°) above 2200 m (Table 1). This compares with a mean of 007° for cirques. Vector strength increases, to over 0.24, only above 2456 m, where headwalls are dominant. Below 2150 m various mean directions occur.

3.2 Bendor

The Bendor Range is well glaciated, with glacial troughs and 222 cirques (Evans and Cox, 2017). Cirque floors average 150 m lower than in Shulaps. Bendor has a ‘glacial’ hypsometric maximum at cirque floor altitudes (Fig. 4). This contrasts with the ‘fluvial’ trend of area increasing linearly downward, at least to the ‘defining pass’ (at 1865 m).

Overall, Bendor gradients peak sharply at 35°. Coinciding with the 05 and 95 percentiles of cirque floor Lowest altitudes at 1790 to 2300 m there is a strong maximum of low gradients, from the extensive cirque floors (Fig. 5). This is complemented by a strong maximum of steep gradients at the same altitudes (Fig. 6). Subdivision (not shown) of steep gradients reveals that for increasingly steep slopes the maximum shifts upwards, peaking around 2300 m – above the mid-altitude of cirque floors – for both 55–65° and >65°. Slopes steeper than 55° are infrequent below 1700 m. Gradients below 20° become more important especially below 1400 m, where there are benches above Cadwallader Creek.

Statistics in Figure 7 show the greater proportions of gradients <20° between 1790 and 2300 m (more noteworthy considering the trend of the proportion reducing with increasing altitude), and of those >45° above 2080 and especially above 2300 m, reflecting floors and headwalls respectively. This is supported by high IQRs between 1790 and 2300 m, but not by SDs.

Although the aspects of cirques and glaciers in Bendor are less azimuthally concentrated than in Shulaps, the glaciation is still strongly asymmetric. Hence above 1900 m, vector means of steep (>40°) slopes are consistently northward, and above 2100 m their vector strengths are above 0.14. The northward mean of 008° is very close to the vector means of cirques (018°) and of modern glaciers (011°). Thus strong and consistent asymmetry of steep slopes, restricted to appropriate altitudes, is a further geomorphometric indicator of cirque headwalls, and therefore of glacial modification.

Table 1 Vector strength and vector mean (with confidence limits) for aspect, by altitude bands, for slope gradients over 40° in the Shulaps Range: from the 12.5 m DEM

Altitude	Strength	Mean	95% limits	Observations
Over 2610 m	**0.287**	**001.0**	358.1 – 003.9	7314
2456 – 2610	**0.240**	**359.6**	357.6 – 001.6	24433
2350 – 2456	**0.180**	**356.5**	353.9 – 359.1	25443
2250 – 2350	**0.179**	**351.0**	348.0 – 354.0	20074
2150 – 2250	**0.214**	341.9	339.0 – 344.8	15095
2050 – 2150	0.136	285.9	280.0 – 291.8	10554
1957 – 2050	0.208	216.8	212.9 – 220.7	10385
Over 2200 m	*0.208*	*356.4*	*355.1 – 357.6*	*85615*

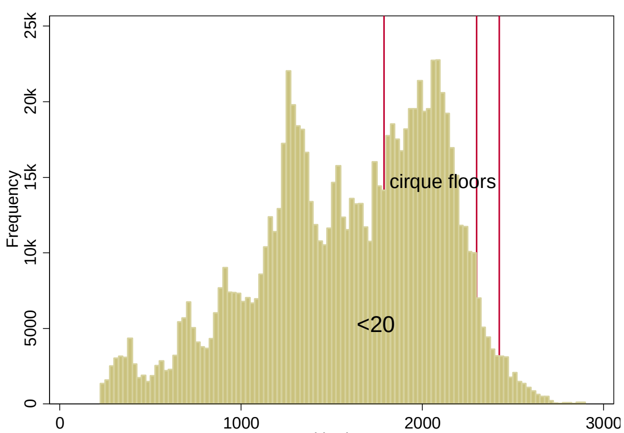

Figure 5 Frequency of gentle slopes (<20°) in the Bendor Range (50 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floors, with frequency peaking at average floor altitude. The lower peak, around 1300 m, relates to valley–side benches along Cadwallader Creek

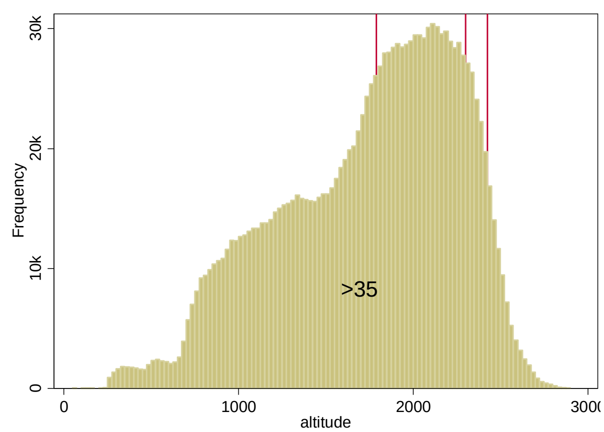

Figure 6 Frequency of steep slopes (>35°) in the Bendor Range (50 m bins). The red lines at 1790, 2300 and 2425 m show the extent of cirque floor altitudes, at which there is a broad maximum of steep (as well as gentle) gradients. Headwalls start from the lowest cirque floors and extend to the highest summits

3.3 Romania

Results from Niculiţa and Evans (2018), using SRTM data for Romania, support those for British Columbia. At present there are no glaciers in the Romanian mountains, but at the Last Glacial Maximum there were many cirque and valley glaciers, in numerous mountain ranges. In the Retezat Mountains of southwest Romania, the 84 cirque floors are mainly 1760–2190 m (5 to 95 percentiles of Modal floor altitude: Mîndrescu et al., 2010; Mîndrescu and Evans, 2014, 2017). This shows in the hypsoclinometric plot as a decline in the lower quartile of gradient, from 1800 to 2100 m altitude (Fig. 8). Median gradient declines (gently) from 1600 to 2050 m, the latter being the median gradient of cirque floor altitudes. The upper quartile and the 95 percentile of gradient rise steeply from 1850 to 2350 m, and the median increases from 2100 to 2400 m: all these show the effects of high gradients from cirque headwalls. The quartiles diverge above 1850 m: the increase in SD and IQR reflects the presence of both low-gradient cirque floors and high-gradient cirque headwalls. There is a relatively small area above 2350 (to 2500 m) and the declining gradients there are due to smoothing as gradients were calculated from a quadratic fitted to a 90 x 90 m window.

Similar results were found for other well–glaciated ranges. The 45 cirque floors of the Rodna Mountains in northern Romania are mainly between 1520 and 1910 m altitude. They show up only weakly, in the lower quartile of gradient falling from 1700 to 1800 m. Headwalls (1620–2280 m) are more evident, in an increasing 95 percentile from 1650 to 2275 m, where (expressed as tangent) it reaches 1.2. Both SD and IQR rise from 1700 to 2300 m, while median gradient rises from 1800 to 2200 m.

Altitude (m)	Mean (°)	Median (°)	SD (°)	IQR (°)	<20° %	>45° %	Observ -ations.
above 2425	36.2	35.7	13.8	16.8	11.3	**22.6**	153k
2300	35.8	35.2	12.8	14.5	9.9	**19.4** headwalls	235k
2080	31.0	31.4	12.6	**15.2** floors	**18.9**	***10.7***	708k
1790	29.6	30.1	12.1	**14.9**	**21.0**	7.8	1053k
1600	29.8	30.4	11.7	13.9	18.8	7.3	538k
1400	28.8	29.5	11.5	14.7	21.7	6.5	457k
Below	28.2	29.1	12.7	17.9	27.0	8.6	1236k

Figure 7 Statistics for Bendor altitudinal classes of gradient, including 1790–2300–2425 m (cirque floors) and 2080–2300 m and up (cirque headwalls)

The Parâng Mountains in the southwest Carpathians have 51 cirques. Again headwalls are more evident than cirque floors, with the 95 percentile of gradient increasing from 0.85 at 1775 m to 1.13 at 2275 m: the upper quartile rises similarly. Median gradient increases from 1950 to 2300 m. SD and IQR increase from 1850 to 2350 m (and 2450 m for SD).

The Romanian results, for 21 ranges, show strong concentrations of high gradients at altitudes of cirque headwalls in fourteen ranges with more than a few cirques. Cirque floors are less evident in hypsoclinometry, presumably because they cover on average only 28% of the map area of a cirque (Mîndrescu and Evans, 2014, 2017). The relevant falling lower quartile is found in six ranges, with weaker indications in five others. 'Glacial signals' in altitudinal distributions of gradients are clearest in the Retezat, Făgăraș, Ţarcu, Maramureş and Rodna Mountains. This is comparable to the ranking (of twelve regions) from seven attributes of cirque quality in Mîndrescu and Evans (2014): from most glacially modified to least, Retezat, Parâng, Făgăraş, Bucegi, Rodna, Lotru–Cindrel, Godeanu, Maramureş, Iezer, Ţarcu, Bihor, Călimani.

Unglaciated ranges in Romania show a variety of altitudinal trends of gradient (Niculiţă and Evans, 2018).

4. Further work

The work on British Columbia is at an early stage and will be extended to further mountain ranges, with differing degrees of past and present glaciation. (Large present–day glaciers cause problems as it is the unknown subglacial topography that is of interest). Data quality needs more detailed study, and it will be useful to compare results from 25 m resolution DEMs with results from these 12.5 m DEMs. Aspect distributions should be analysed in relation to gradient as well as altitude. Finally, several measures of surface curvature can be analysed in relation to altitude.

5. Conclusions

The strong glacial modification of the Bendor Range shows in a high percentage of steep slopes (headwalls) at and above cirque floor altitudes, and of gentle slopes (above the upward decreasing trend) at cirque floor altitudes.

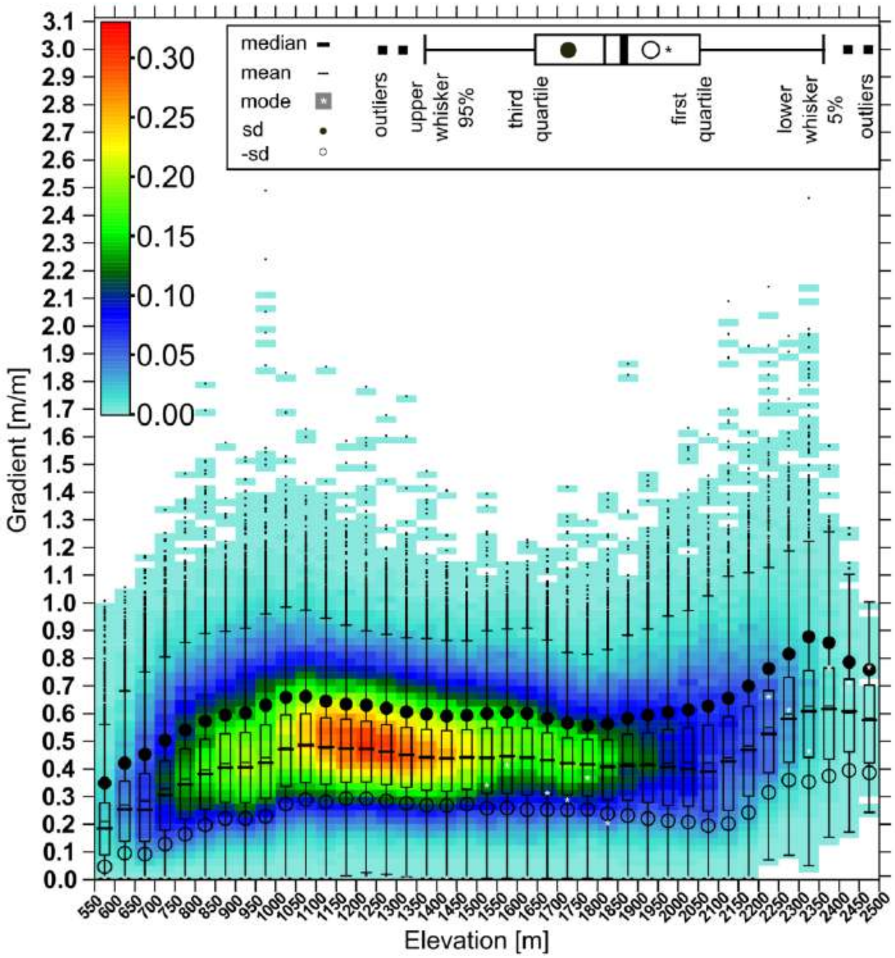

Figure 8 (from Mihai Niculiţă) Combined boxplots and density distributions for the Retezat Mountains, southwest Carpathians. The boxes represent the Interquartile Range (IQR), from lower to upper quartile. The circles show one standard deviation (SD) above the mean (black) and one below (open). Colour shows percentage of observations, for bins of 50 m altitude x 0.025 gradient. Note that gradient (tangent) of 1.0 = 45°

Steep (and especially steepest) slopes are concentrated at cirque altitudes, increasing mean, median, SD and IQR especially above cirque floors. There is only a small increase of IQR and SD at cirque floor altitudes. The hypsometric maximum is at cirque floor altitudes, unlike the expectation for fluvial topography.

The Shulaps Range is asymmetrically glaciated with fewer cirques and very short troughs. It shows a strong secondary mode of steep slopes above 2100 m altitude; but the 'glacial' signal in morphometry is much weaker than for Bendor, reflecting its lesser degree of glacial modification. This is due to a former ELA which is higher in Shulaps, whereas summits are of comparable altitude. The present–day ELA is also higher in the Shulaps, and its lower precipitation may also make its glaciers less effective both today and in the past.

These results are supported by the Romanian evidence in Niculiţă and Evans (2018). Romanian ranges can thus be ranked by degree of glacial modification, comparably to the ranking from specific geomorphometry of cirques in Mîndrescu and Evans (2014). In general, low gradients at cirque floor altitudes become clear only in well-glaciated ranges with high densities of cirques. The most general morphometric effect of glaciation is the increase in steep slopes at cirque headwall altitudes. This usually feeds through to increased variability and averages of gradient: SD, IQR, mean and median. Complications can arise where there are low-gradient summit surfaces, as in the Godeanu and Ţarcu Mountains, or where extensive gentle slopes are found below cirque floors as in the Shulaps Range.

Slope aspects are much more azimuthally concentrated at the altitudes of headwalls. Vector means are northward above 1900 m in Bendor and 2200 m in Shulaps. Vector strengths for slopes on headwalls are >14% in Bendor above 2100 m and >18% in Shulaps above 2200 m. These are similar to vector means for cirque aspects and glacier aspects. Likewise in the English Lake District, slopes >45° at high altitude have a vector mean aspect of northeast, as do cirques and a vector strength of 37%. These results are characteristic of mountains glaciated asymmetrically, and give further objective evidence of a glacial imprint.

Although these results are preliminary, and analyses of further mountain ranges are required, it is possible to arrive at judgements on the three hypotheses. The first, that there are more gradients <20° at cirque floor altitudes, is weakly confirmed. The second, that there are more gradients >35° above cirque floors (representing cirque headwalls) is strongly confirmed, and in the British Columbian examples applies especially to gradients >45°. The third, that higher standard deviations and interquartile ranges of gradients occur at cirque floor altitudes (because the altitude ranges of headwalls and floors overlap), is strongly confirmed. Thus it may be possible to rank mountain ranges by the degree of glacial modification, using several approaches of general geomorphometry.

Acknowledgements

I am grateful to the German Aerospace Centre (DLR) for providing TanDEM–X DEM data for the Bridge River District under project DEM_METH1517, to Dave Milledge for processing the data, to Nick Cox for Stata programming and to Mihai Niculiţă for permission to use Figure 8.

References

Barr ID, Spagnolo M. 2015. Glacial cirques as palaeoenvironmental indicators: Their potential and limitations. *Earth-Science Reviews*, **151**: 48–78. http://dx.doi.org/10.1016/j.earscirev.2015.10.004.

Crest Y, Delmas M, Braucher R, Gunnell Y, Calvet M, Team ASTER 2017. Cirques have growth spurts during deglacial and interglacial periods: evidence from 10Be and 26Al nuclide inventories in the central and eastern Pyrenees. *Geomorphology*, **278**: 60–77. https://doi.org/10.1016/j.geomorph.2016.10.035.

Egholm DL, Nielsen SB, Pedersen VK, Lesemann JE. 2009. Glacial effects limiting mountain height. *Nature*, **460**: 884–887. https://doi.org/10.1038/nature08263.

Evans IS. 1979. *An integrated system of terrain analysis and slope mapping*. Final report on grant DA–ERO–591–73–G0040, University of Durham, England.

Evans IS. 1990. Climatic effects on glacier distribution across the southern Coast Mountains, B.C., Canada. *Annals of Glaciology*, **14**: 58–64.

Evans IS, Cox NJ. 2017. Comparability of cirque size and shape measures between regions and between researchers. *Zeitschrift für Geomorphologie*, **61**(Suppl. 2): 81–103. https://doi.org/10.1127/zfg_suppl/2016/0329.

Evans IS, Hall AM, Kleman J. 2015. Glacial cirques and the relationship between equilibrium line altitudes and mountain range height: COMMENT. *Geology*, **43** (e366). DOI: 10.1130/G36667C.1.

Kühni A, Pfiffner OA. 2001. The relief of the Swiss Alps and adjacent areas and its relation to lithology and structure: topographic analysis from a 250–m DEM. *Geomorphology*, **41**: 285–307.

Minár J, Evans IS, Krcho J. 2016. *Geomorphometry: Quantitative Land–Surface Analysis (2nd. Edition)*. In: Reference Module in Earth Systems and Environmental Sciences. Elsevier, Amsterdam. DOI: 10.1016/B978-0-12-409548-9.10260-X.

Mîndrescu M, Evans IS. 2014. Cirque form and development in Romania: allometry and the buzz–saw hypothesis. *Geomorphology*, 208: 117–136. http://dx.doi.org/10.1016/j.geomorph.2013.11.019.

Mîndrescu M, Evans IS. 2017. *Glacial cirques in the Romanian Carpathians and their climatic implications*. In: Rădoane M, Vespremeanu–Stroe A. (eds.): Landform Dynamics and Evolution in Romania. Springer Geography, 197–213. DOI 10.1007/978-3-319-32589-7_9.

Mîndrescu M, Evans IS, Cox NJ. 2010. Climatic implications of cirque distribution in the Romanian Carpathians: palaeowind directions during glacial periods. *Journal of Quaternary Science*, **25** (6): 875–888. DOI: 10.1002/jqs.1363.

Mitchell SG, Montgomery DR. 2006. Influence of a glacial buzzsaw on the height and morphology of the Cascade Range in central Washington State, USA. *Quaternary Research*, **65**: 96–107.

Niculiţă M, Evans IS. 2018. Effects of glaciation on the clinometry and hypsometry of the Romanian Carpathians. *Geomorphometry*, 2018. PeerJ Preprintshttps://doi.org/10.7287/peerj.preprints.27076v1.

Robl J, Prasicek G, Hergarten S, Salcher B. 2015. Glacial cirques and the relationship between equilibrium line altitudes and range height. *Geology*, **43** (e365). http://dx.doi.org/10.1016/j.gloplacha.2015.01.008.

Robl JG, Prasicek G, Hergarten S, Stüwe K. 2015a. Alpine topography in the light of tectonic uplift and glaciation. *Global & Planetary Change*, **127**: 34–49. http://dx.doi.org/10.1016/j.gloplacha.2015.01.008.